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An investigation into the prediction of field strength
'THE GUILDFORD EXPERIMENT'

No. 1970/26

Research Department, Engineering Division
THE BRITISH BROADCASTING CORPORATION

RESEARCH DEPARTMENT

AN INVESTIGATION INTO THE PREDICTION OF FIELD STRENGTH: 'THE GUILDFORD EXPERIMENT'

Research Department Report No. **1970/26**
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Research Department Report No. 1970/26

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AN INVESTIGATION INTO THE PREDICTION OF FIELD STRENGTH: 'THE GUILDFORD EXPERIMENT'

Summary

A preliminary investigation has been conducted into the prediction of field strength, of both wanted and interfering signals, at u.h.f. This report summarises the conclusions and proposes further work.

Terrain data for an area 25 miles (40 km) in diameter centred on Guildford were stored in the computer and used for the prediction of field strengths by various methods. The results were compared with detailed measurements of five transmissions in the Guildford area.

The results demonstrated that existing methods of interference prediction require improvement, and that the prediction of wanted and interfering signals ought to be combined. A method of doing this, based on a stored bank of terrain data for the whole of the U.K., is now being developed.

1. Introduction

Because of the limited extent of the spectrum allocated to broadcasting, transmitting stations must often be co-channelled, and it is important to ensure that mutual interference is kept to a minimum. Where there are considerable distances between the co-channelled stations (an open network), interference is likely to appear only occasionally, and is largely dependent upon tropospheric conditions over the propagation path. In a closely-spaced network, however, such as that now being planned for the u.h.f. service, the separation distances may be extremely small, and interference could be continuous because the signals will not be materially affected by tropospheric fading. Therefore, in an open network the risk of interference is statistically small, and the field strength required at the great majority of receiving sites in order to obtain an acceptable service is governed by receiver noise levels and other constants. In a dense network, the majority of the viewers could be affected by interference, the level of which will vary from location to location. In these circumstances it becomes increasingly important to relate the levels of the wanted signal and the interference at as many receiving locations as possible.

In developing the plans for the u.h.f. service in the United Kingdom the need for greater precision in calculating co-channel interference (c.c.i.) has been recognised. Methods have been devised which give much greater accuracy than was attainable with earlier techniques. Nevertheless, it was suspected that full exploitation of the u.h.f. broadcasting spectrum would be achieved only by including much more detail in the field strength calculation than hitherto. To confirm this the 'Guildford experiment' was initiated in January, 1969. Three principal objectives were specified namely,

(i) to determine the accuracy of prediction methods currently used by Research Department,

(ii) to see if additional data could be provided which would improve prediction accuracy, and

(iii) to extend our knowledge of the distribution of and correlation between measurements of transmissions from different sources.

It was also considered that a very important by-product of the experiment would be an assessment of the acceptability or otherwise of prediction methods for present and future broadcast planning work.

The city of Guildford and its environs were chosen for the experiment firstly because it was practicable to measure several u.h.f. signals in the area, secondly because it included different types of terrain typical of the topography of the United Kingdom, and thirdly because a great deal of earlier experimental work connected with u.h.f. field strength measurement had been carried out there. It is also within reasonable distance of Kingswood Warren.

The first part of the experiment consisted of the field strength measurement of five u.h.f. transmissions which could be received in the area. Additional measurements from another investigation have also been used to provide data regarding the correlation in time of signals from different sources, because the Guildford surveys could not give adequate information in this respect.

The basis of the prediction work was a detailed map of the terrain within a circle 25 miles (40 km) in diameter, centred on Guildford. This information was stored in a computer, so that ground profile information for any propagation path within the area could be extracted at will. The store was later extended to include path data to the transmitting sites outside the circle.

Various prediction methods have so far been examined, and the results compared with the measurements. Discrepancies in present techniques have been identified, and improvements are now being devised.

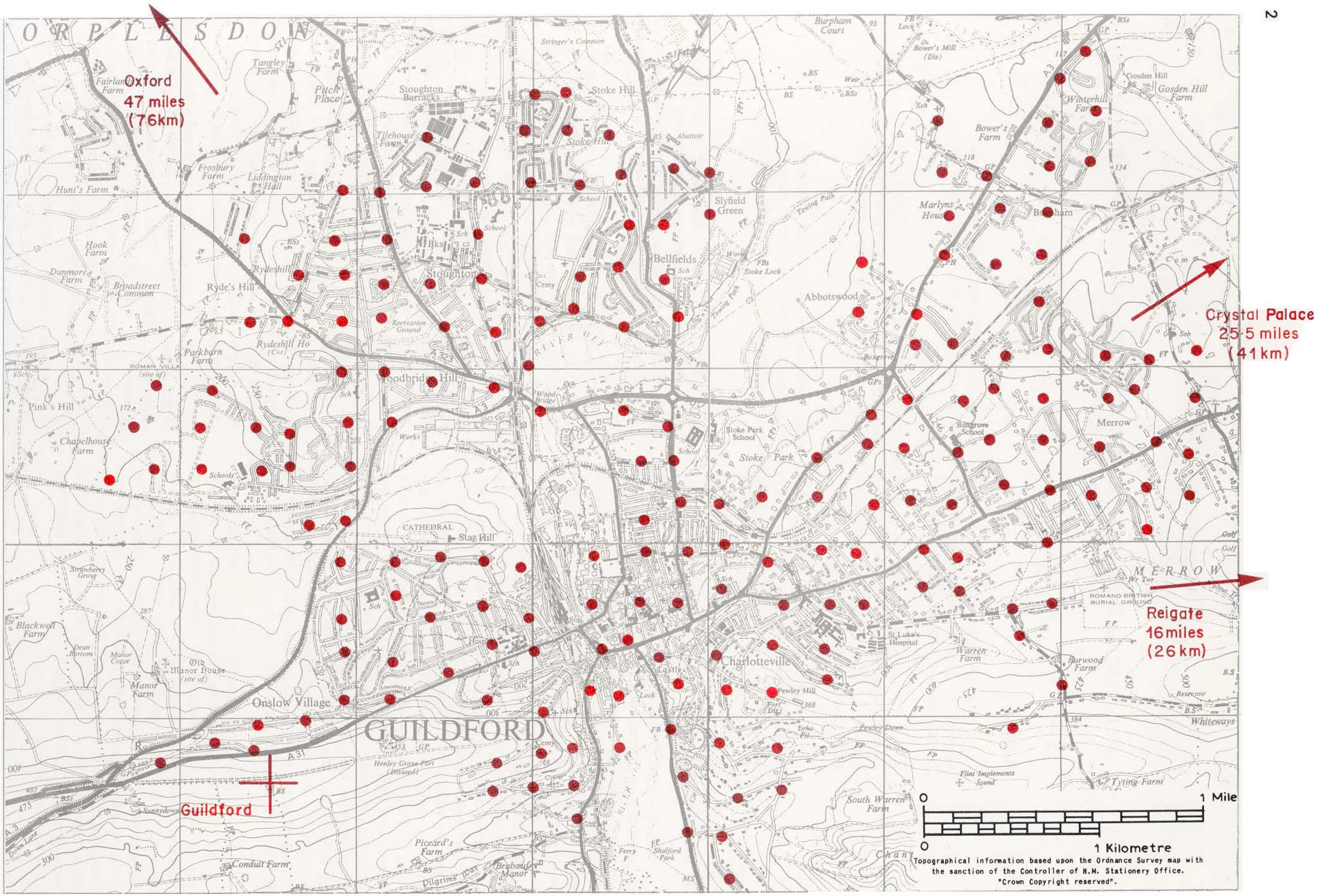

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Fig. 1 - Location of measuring points — 1969

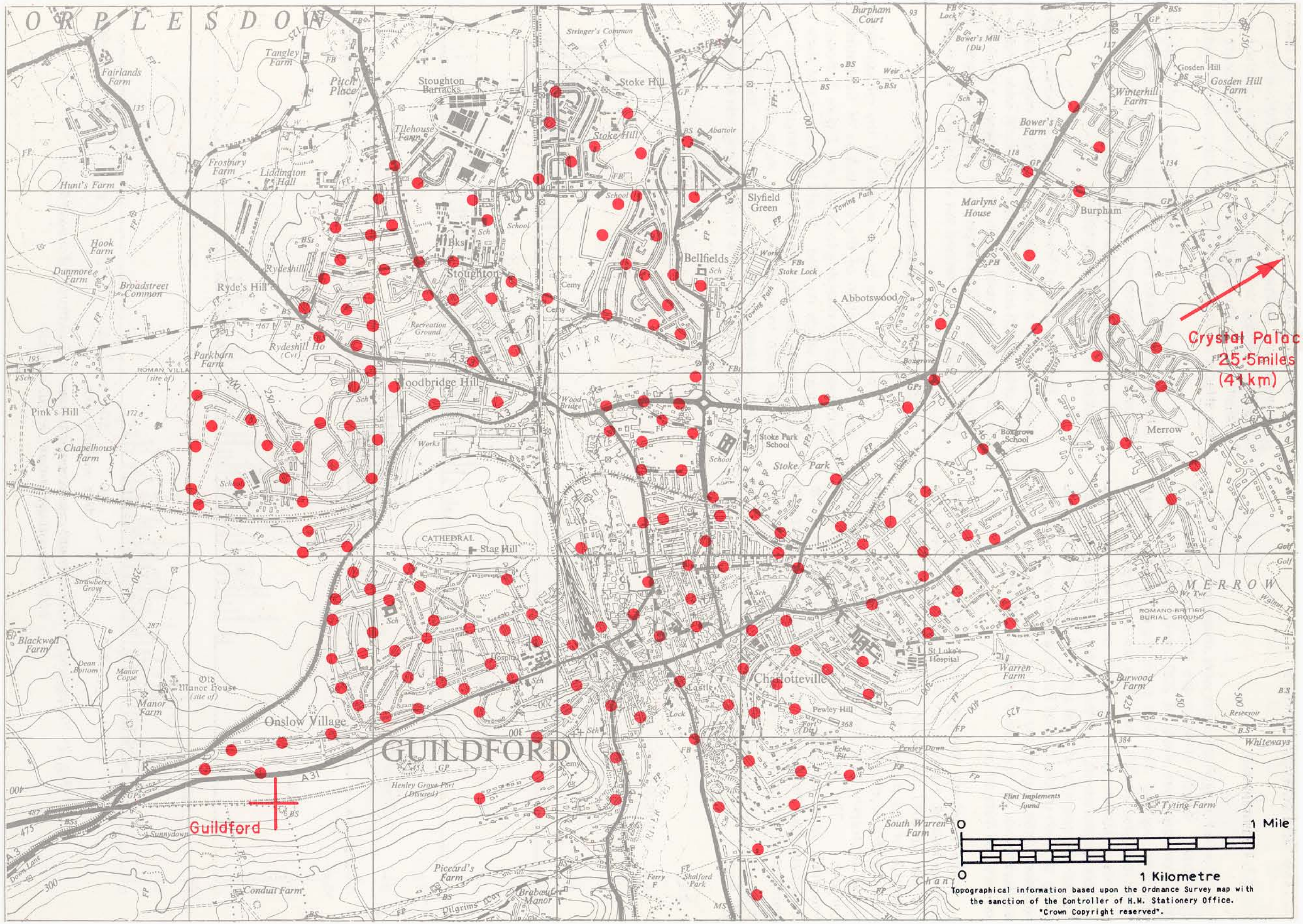

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Fig. 2 - Location of measuring points — 1957

2. The field strength surveys

2.1. Measurements

Five u.h.f. transmissions were measured in the Guildford area; details of these are shown in Appendix I.* Measurements were made at 200 receiving locations, and wherever possible the field strengths of the five signals were measured at each one. In a few cases the signal from a distant station was too weak or variable to allow reliable measurement, but this factor did not significantly reduce the quantity of valid data. A static recording was made of both of the Crystal Palace transmissions, and this revealed little fading throughout, but repeated survey measurements of the more distant Oxford station did reveal some fluctuation.

The receiving locations were distributed over the built-up area at a density of about 35 to the square mile (14 per sq. km), as shown in Figure 1. An important objective of the measurement programme was to provide evidence for comparison with predictions, and samples spread uniformly over the district were suitable for this purpose. The question of receiving site selection is important when consideration is given to translating the measurements into the output which displays field strength distribution over an area, e.g., a field strength contour map, and this aspect is dealt with later in this report. At each of the receiving locations selected in Guildford the field strength recorded was either the mean value observed over a short run, or the average of five spot measurements, thus the effects of local standing wave patterns were minimised.

In addition to the surveys made for the experiment, a further 200 results from an earlier survey were also used. These were measurements made in 1957 of the experimental u.h.f. service from Crystal Palace, and Figure 2 shows the locations of these receiving sites.

Results obtained from a separate measurement programme which is being used to investigate mixed land/sea path propagation across the English Channel were employed to study the correlation in time between signals from various sources. This experiment is still in progress, and further work is to be carried out on this part of the study.

2.2. Analysis of measurements

The first stage in the analysis of the measurements was the examination of the distribution of field strength with respect to receiving location, and Figure 3 shows the histograms which resulted. It will be realised that these do not illustrate the full range of field strength over the city, because each measurement is the mean of a local distribution, as described in the previous section. These recorded values are those which the measuring engineer considers are

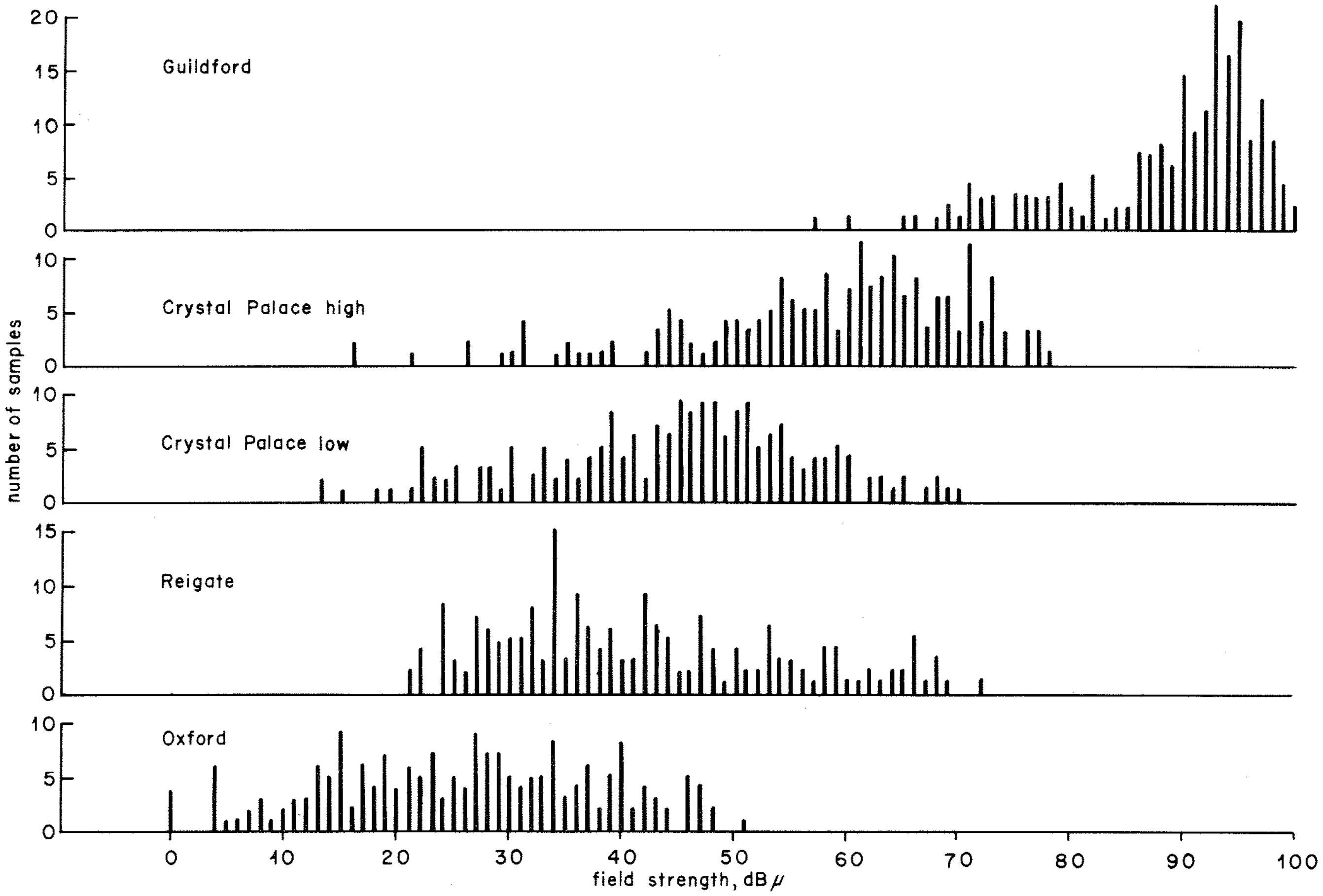

Fig. 3 - Histograms of field strength measurements made in Guildford. Equated for an effective radiated power (e.r.p.) of 1 kW

representative of the particular area. It is clearly impracticable to make measurements at every potential receiving location, but it is desirable to know how the signal will vary with movement away from the site selected. Furthermore, because these values were to be used to judge the success of prediction, it was important to evaluate the error of measurement itself. Thus the next stage in the analysis consisted of defining the accuracy of the measurement and the influence of movement.

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* Measurements were made by R.I. Black, I.G.R. Morgan and J.B. Bush.

Considering firstly the accuracy of measurement, it is important to note that what we are dealing with here is the ability to measure field strength, and not the process of producing a field strength map or some other form of output from the measurement procedure. The latter stage can involve all sorts of subjective assessments, and will be dealt with later in the report. It is convenient to refer to the factor now considered as 'basic error', i.e., variations in measurements repeated at a particular receiving site, with the receiving aerial at the identical position in space. This will reveal any slight differences of calibration, and any subsequent error introduced during the process of measurement. To establish this from the Guildford results about 100 of the survey measurements made of the Guildford relay station were repeated. The local station was selected for this purpose in order to minimise any difference which might otherwise have been introduced by fading. Figure 4 is a histogram of the differences, the distribution having limits of −5·0 dB to +9·6 dB, with a standard deviation of about two decibels. About 93% of the results were within ±3 dB. Of course, the values measured on the road will differ from the values actually used by the viewers, but this feature is not dealt with in this report. Road measurements are taken to be representative of the situation, and for the purpose of comparison they have been used as the ultimate reference.

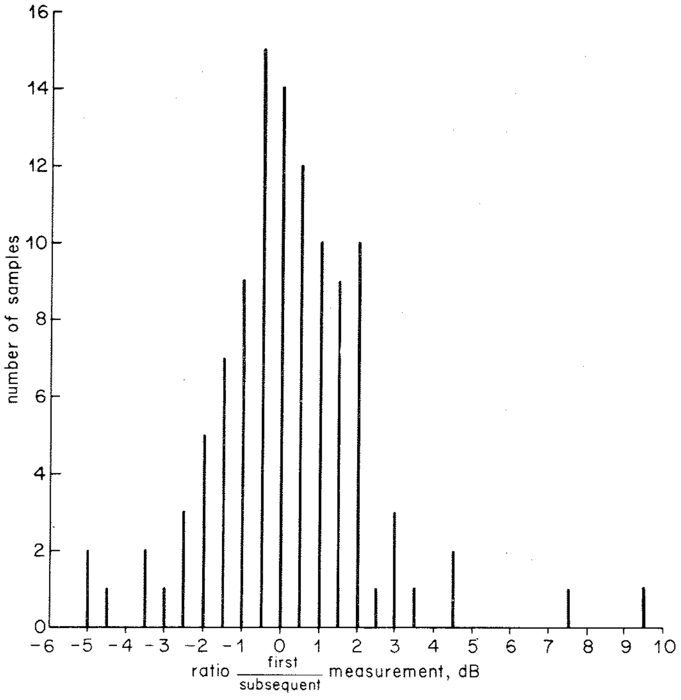

Fig. 4 - Basic error of measurement : histogram showing differences between first and subsequent measurement at each of 109 receiving sites

It is necessary, therefore, to observe in any comparison between measurement and prediction the basic error shown above to have a standard deviation of about two decibels. If we assume a Gaussian distribution, in which 99% of the samples will lie within $\pm 2{\cdot}5\sigma$ of the median, it is reasonable to expect that about 99% of the measurements, if repeated, would lie within ±5 dB of the previous observations. This particular conclusion makes an interesting comparison with the results of two other field strength investigations.

Work by the Post Office during the 1957/58 u.h.f. field trials showed that field strength measurements made within a small range of aerial movement produced field strength variations of about ±5 dB. The movement was limited to about three feet (one metre) in any direction with the receiving aerial raised to a height of about 30 feet (9·1 m). During the same tests, work within BBC Research Department yielded the curve shown in Figure 5, in which the extent of field strength variation over small towns is plotted as a function of the depth of terrain undulations within the same area. The intercept of this curve with the y-axis occurs at about 9·5 dB, which again suggests that measurements made over a small area on flat ground produce variations which generally lie within an overall range of 10 dB.

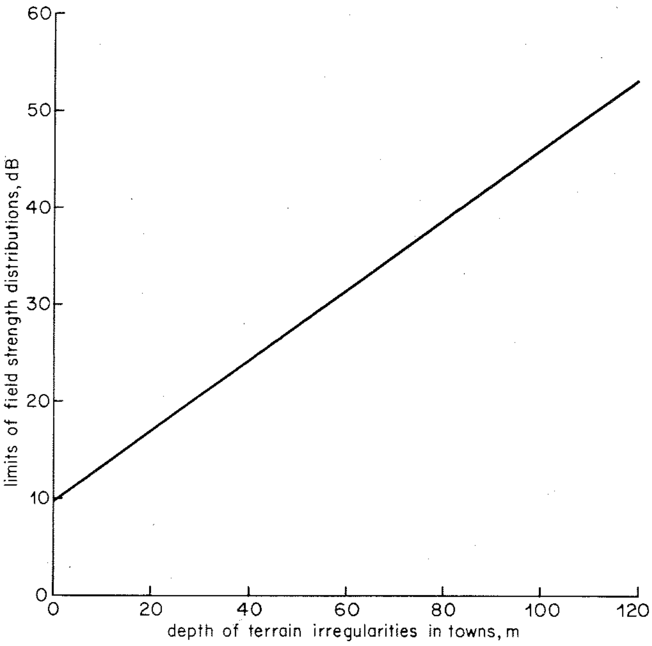

Fig. 5 - Limits of u.h.f. field strength distributions in towns as a function of depth of terrain irregularities. Derived from results of 1957/1958 u.h.f. field trials.

Of course, the results discussed in the previous paragraph are purely empirical. Elementary theory dictates that the geometry of the propagation path can produce variations of much greater extent. However, the great majority of the measurements support the premise that these are useful overall limits, and on this evidence it is concluded that an accuracy of ±5 dB for 99% of the samples is the most that can be expected of the best method currently used, i.e., measurement. This margin must therefore represent the ultimate accuracy of prediction.

The basic error dealt with above has covered variation of field strength within a very small area, and it is important to see how this margin will change with movement beyond this distance. To obtain an estimate of this, measurements were again repeated at about 100 points, but this time at locations slightly different from those used for the previous survey. The new sites were generally about 20 yards (18 m) from the original points, and the differences observed in this test are shown in Figure 6. It is interesting to note that the variation still approximates to a normal distribution, the observed limits being −11·4 dB to +14·4 dB with a standard deviation of about 4·5 dB. Thus, applying the same approximation as before, it is reasonable to expect that about 99% of the measurements, if repeated within 20 yards of the sites of the first survey, would lie within ±11 dB of the first results. It will be seen from this that the effect of only a small movement has been quite considerable, and this sensitivity must be remembered when comparing measurement and prediction.

The Guildford measurements were also analysed to investigate the correlation (ρ_L) in location between the various transmissions. So far this has been done in two ways. Firstly the results obtained from the 200 points were joined together to simulate a continuous measurement run around the city, following the hypothetical route shown in Figure 7. The gradient of the field strength curve has been correlated with various parameters, such as the terrain clearance angle.* Secondly, ρ_L was checked by use of the standard formula

$$\rho_L = \frac{\frac{1}{N}\Sigma(x-\overline{x})(y-\overline{y})}{\sigma_x\,\sigma_y}$$

where N is the number of pairs correlated

$x, y,$ are the field strength values of transmitters X and Y

$\sigma_x, \sigma_y,$ are the standard deviations of the field strength distributions.

Table 1 shows the results obtained by this process, and it will be seen that the greatest correlation is attained by comparison of the two Crystal Palace transmissions. Figure 8 shows the correlation in terms of the difference in bearing between the sources compared. As expected, it can be seen that as the angle between the correlated sources narrows, the correlation coefficient increases.

TABLE 1

Transmitter X	Transmitter Y	Correlation ρ_L
Guildford	Crystal Palace (high)	0·347
Guildford	Crystal Palace (low)	0·303
Guildford	Reigate	0·43
Guildford	Oxford	0·045
Crystal Palace (high)	Crystal Palace (low)	0·948
Crystal Palace (high)	Reigate	0·748
Crystal Palace (high)	Oxford	0·344
Crystal Palace (low)	Reigate	0·715
Crystal Palace (low)	Oxford	0·42
Reigate	Oxford	0·19

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* The derivation and use of this angle is described in Reference 1.

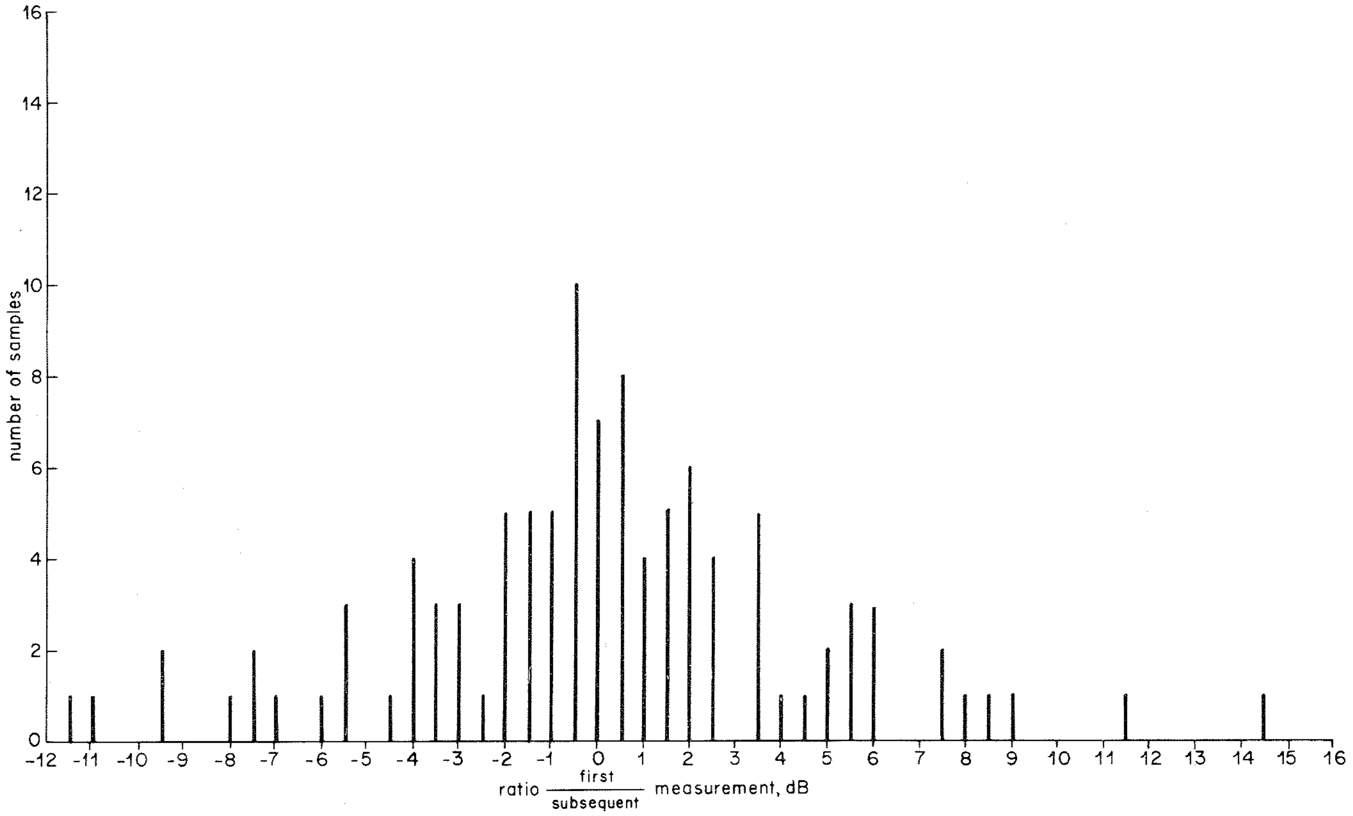

Fig. 6 - Histogram showing differences between two measurements made within 20 yards (18 m). Observations made at 105 receiving sites

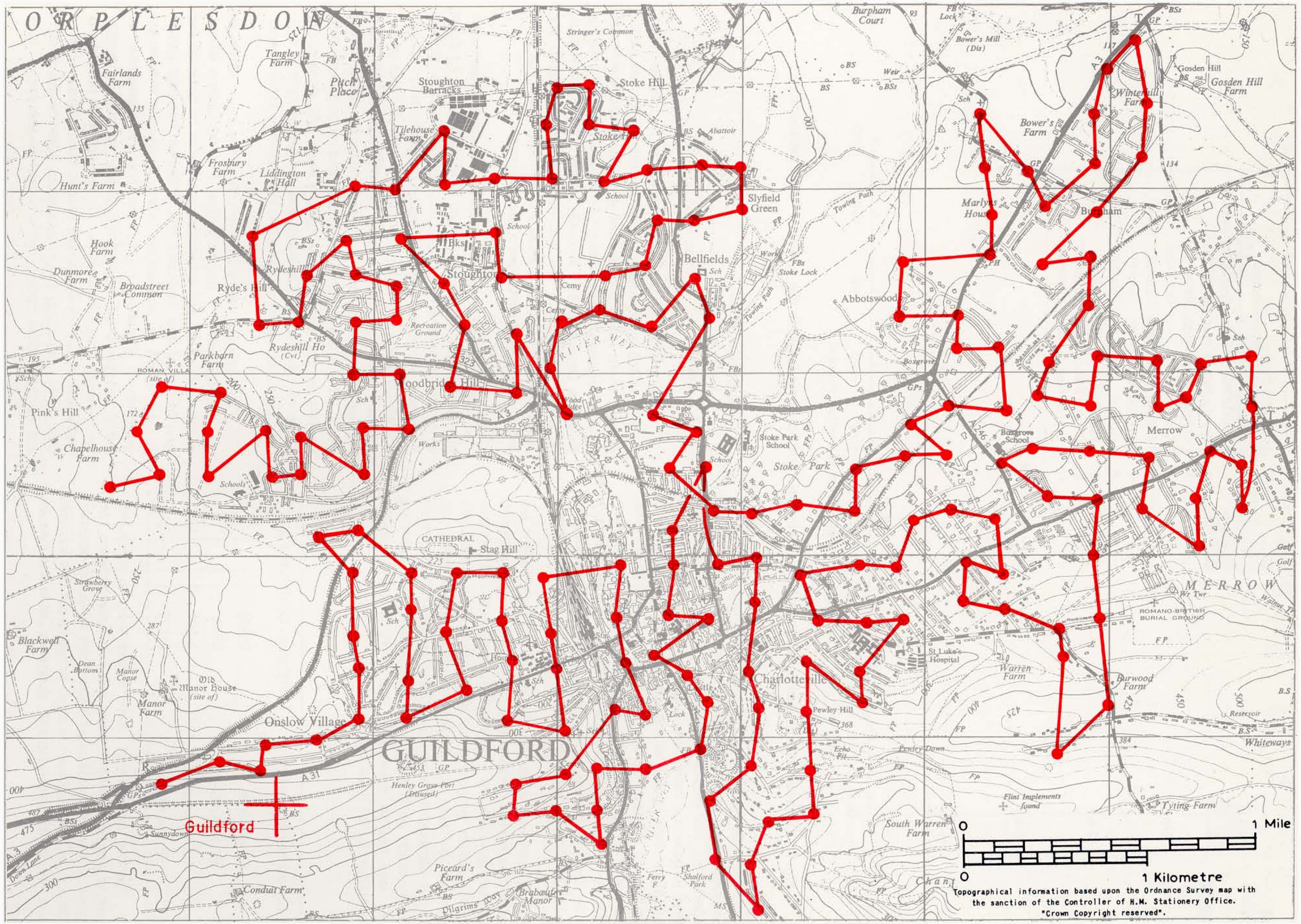

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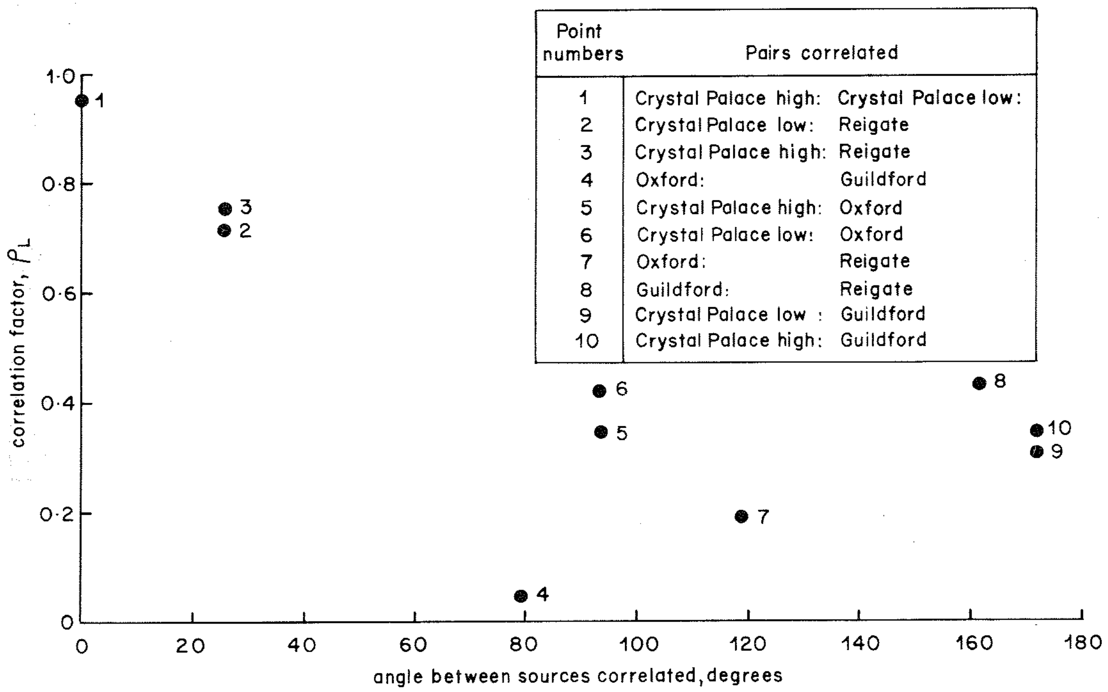
Fig. 7 - Points measured in 1969 joined to simulate continuous run



Point numbers	Pairs correlated	
1	Crystal Palace high:	Crystal Palace low:
2	Crystal Palace low:	Reigate
3	Crystal Palace high:	Reigate
4	Oxford:	Guildford
5	Crystal Palace high:	Oxford
6	Crystal Palace low:	Oxford
7	Oxford:	Reigate
8	Guildford:	Reigate
9	Crystal Palace low :	Guildford
10	Crystal Palace high:	Guildford

Fig. 8 - Location correlation coefficient (ρ_L) as a function of the angle between the sources of the transmissions

The investigation into correlation in time (ρ_T) between two signals has been proceeding in parallel with the main experiment, and results from another propagation measurement programme have been used for this. The principal objectives were to define the relationship between ρ_T and the bearing between the sources correlated, and to establish the variation of ρ_T with the duration of observation. Measurements are still being assembled, and much remains to be done, but some early results so far obtained support earlier qualitative assumptions concerning the two features.

On present evidence, the correlation coefficient between two signals decreases as the period of observation is reduced, as expected. Insufficient analysis has so far been carried out to propound the relationship, but an example is shown in Table 2. Measurements of signals from two French stations (le Havre and Caen) made at Christchurch on the south coast have been compared. The recording time was broken down into the intervals shown, and a correlation factor obtained for each.

TABLE 2

Period of Observation	Correlation Coefficient ρ_T
60 minutes	0·886
30 minutes	0·86
10 minutes	0·821
2 minutes	0·772

Similar preliminary work shows that, as expected, there is greater chance of correlation in time between two signals if they traverse substantially the same transmission path, i.e., ρ_T increases as the angle between the two sources, measured at the receiving site, decreases (as in the case of ρ_L).

3. The predictions

3.1. General

The prediction work undertaken in connection with the Guildford experiment can be considered in two parts. Firstly, there is the comparison with the measurements of results obtained from existing prediction methods used by Research Department. Secondly, there is the examination of other methods. The second stage has included the application of various established techniques, and has now led to development work on a new approach.

Existing prediction work within Research Department consists of two distinct methods which are used to assist with the planning of the u.h.f. service in the United Kingdom. Both have been designed for completion using a digital computer. The first predicts the service area of the station, this being undertaken by calculating the field strengths along a number of radials from the transmitting site.[2] This is a very detailed process, and requires data concerning terrain heights, buildings and trees. At present, the range of calculation is limited, and the programme is only used to predict some of the u.h.f. relay station service areas.

The second programme predicts the c.c.i. levels in each service area.[3] The output of this calculation allows suitable channels and transmitting sites to be selected for new stations, and indicates the effective radiated power (e.r.p.) which is permissible without causing intolerable interference elsewhere. This requires the assessment of many thousands of propagation paths, varying in lengths up to hundreds of kilometres. It has not been possible to include as much topographical data in this programme as in that which calculates the service areas, and for this reason the method relies upon a more statistical approach. It is important to note at this point that an essential part of the planning work consists of the comparison of results obtained from the two programmes, i.e., in any area the level of the wanted service is checked to ensure that it exceeds the c.c.i. level by the appropriate margin. If the service area is measured rather than predicted, then the measurements are compared with the c.c.i. predictions. This feature of the process will be discussed later in the report.

It was realised that the examination of predictions connected with the Guildford experiment could involve many thousands of propagation paths. To eliminate the need to prepare each of these, and, at the same time to provide other terrain data which might be of interest, data evaluating the terrain heights within a 25-mile (40 km) circle centred on Guildford were stored in the computer. The digital terrain coder[4] was used to prepare these data, and because programmes already existed to deal with output from this equipment, it was decided to base the height data on a grid having the density prescribed by these programmes, viz., 0·1 mile (0·16 km).

The area was divided into 0·1 mile strips from west to east, and the contour information along each of these lines was read off on the coder. The output was processed to produce height information at horizontal intervals of 0·1 mile, and these values were then stored. To establish the accuracy of the process, a comparison was made between calculated heights and values read directly from the maps. The result of this is shown in Figure 9. A subsequent investigation into the causes of the larger errors illustrated the difficulties of extracting height data from Ordnance Survey maps with complete accuracy. In this context, a visit to the Ordnance Survey headquarters provided some interesting information concerning map accuracy, and a note summarising the results of this visit forms Appendix 2.

A three-dimensional model of the terrain store was prepared from the computer print-out, and a photograph of this is shown in Figure 10.* Although the mass of the terrain storage was contained within the circle, data were also obtained for corridors leading to transmitting stations included in the experiment which were outside the circumference, so that full information was available for all the propagation paths involved.

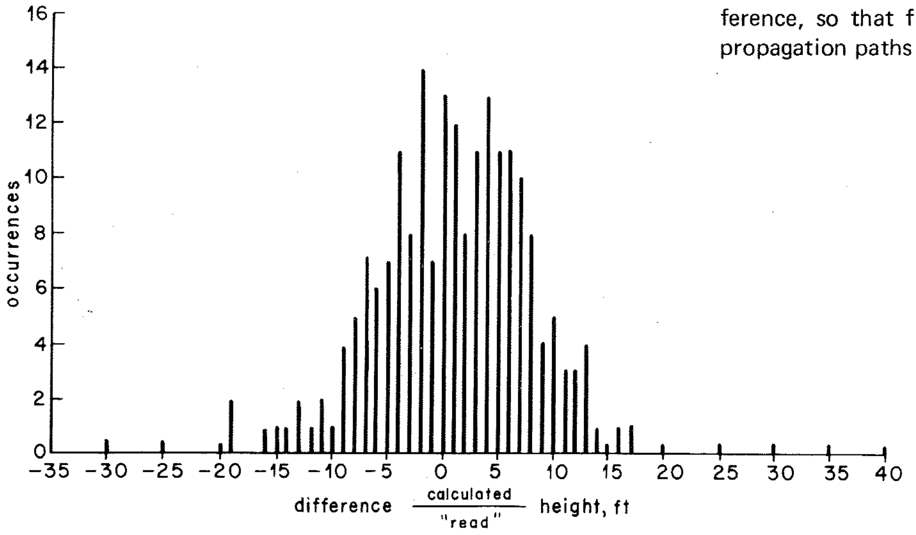


Fig. 9 - Histogram of differences between heights calculated from stored grid and values read from map

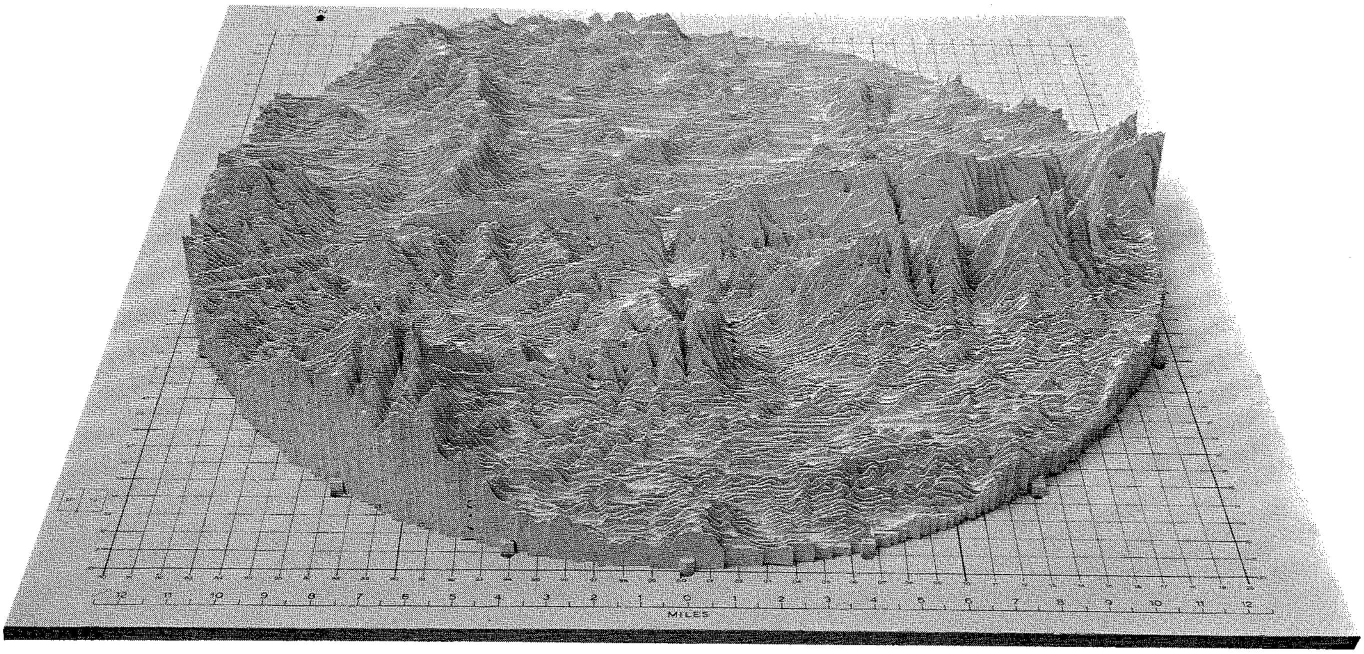


Fig. 10 - Model of terrain grid constructed from computer print out. Density of stored height data = 0·1 mile (0·16 km)

* This model was constructed by I. Rhodes and Miss F.J.C. Gravatt.

3.2. Results of predictions using existing BBC methods

3.2.1. The service area prediction method

As mentioned above, the range of the service area prediction method is limited, therefore in the Guildford experiment it was only used to calculate the field strengths of the Guildford station. The result of comparing the predictions with the measurements for the 200 receiving sites is shown in Figure 11. The distribution is skew, and at first sight was somewhat disappointing, because it has a standard deviation of about 6·5 dB. The prediction overstated the field strength by 10 dB or more at 25 of the points, of which 24 are to the east of the transmitting site in parts of Guildford where the houses are well separated and where there is a large number of trees. Only one of the over-estimated results is in the north of the city, where the housing is denser and where there are fewer trees. The presence of trees is sometimes indicated on the Ordnance Survey maps, although aerial photographs were found to be more useful for this detailed study. Although we cannot yet be sure that failure to identify the presence of trees is responsible for the important errors in this Guildford prediction, it is a point which is receiving further attention. It is worthy of note that in the northern part of the town the method resulted in a measured/predicted distribution having a standard deviation of about 4 dB, which compares favourably with the result obtained for measurements repeated within 20 yards (18 m).

3.2.2. The c.c.i. calculation method

The c.c.i. calculation was used to predict the field strengths of all five transmissions at the 200 receiving locations in Guildford. The results of comparison with measurements are shown in Figure 12, and it will be seen that with the exception of Crystal Palace (high aerial) and Guildford, the results produce distributions with median values above zero decibels, i.e., the tendency is to over-estimate the field strength. Subsequent work has shown that much of Guildford is within line of sight of the high aerial at Crystal Palace, so that the use of the 'clutter loss' factor included in this particular prediction method results in the application of too much attenuation. The result for the Guildford station itself is inconclusive, because this type of short-path calculation is outside the scope of the present c.c.i. prediction.

Inspection of the results for the other three stations showed that whereas the predicted values gave good agreement with measured results for higher receiving sites, calculations for locations in the valleys were not of the same accuracy. This fact, combined with the conclusion concerning the Crystal Palace (high aerial) results, indicate that the c.c.i. method is dealing adequately with 'median' locations, but is incapable of coping with open sites or those which are very shielded. The former may be attributed, as mentioned above, to unwarranted application of the clutter loss; the latter to the limitation imposed on the terrain clearance attenuation curve. This limit (amounting to a maximum loss of 26 dB) was originally adopted because it was felt that it would be unwise to count upon too much attenuation behind an obstacle. A signal from an unwanted source could be reflected from a surface behind the receiving site and this could cause interference.

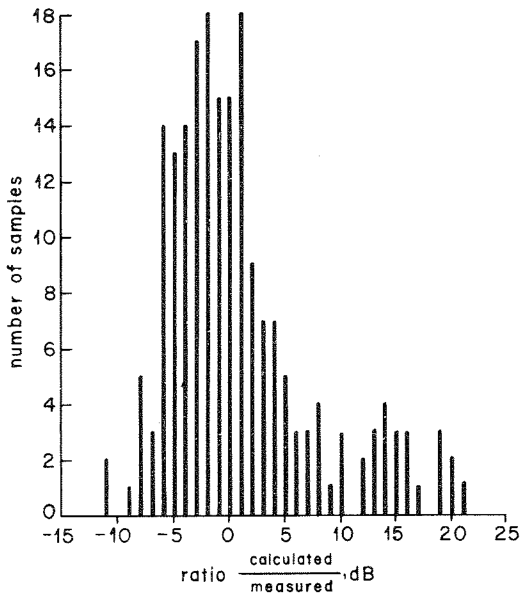


Fig. 11 - Histogram of differences between measured field strengths and those calculated using the service area prediction method

3.3. Other prediction methods

The examination of other prediction methods has passed through three stages. Firstly (and this applied solely to the c.c.i. prediction method) there was an attempt to improve the technique whilst still retaining the basic approach. Secondly, other established techniques developed elsewhere were examined. Finally a development stage was reached, in which the results of the whole work have been and are being used to examine the possible development of a new method. These three stages are now described.

In order to remedy the weaknesses of the c.c.i. method the use of an additional local correction was investigated. It was thought that such a factor, in defining local variations, could also replace the present 'urban loss', a constant used to account for the shadow loss introduced by buildings in the vicinity of the receiving site. An additional local correction factor was derived, and did produce a worthwhile improvement, but it did little to overcome the problem illustrated by the Crystal Palace (high aerial) result. Because this station was beyond the range of 10 miles (16 km) — the distance within which terrain information is used to apply corrections in the c.c.i. method — the fact that the transmitting aerial was within line of site was not taken into account. It was clear that worthwhile improvement in the basic c.c.i. method could only be realised by providing much more information about the propagation path. Having once reached this conclusion, it was pertinent to consider if, given full terrain data, some other method might not be more accurate.

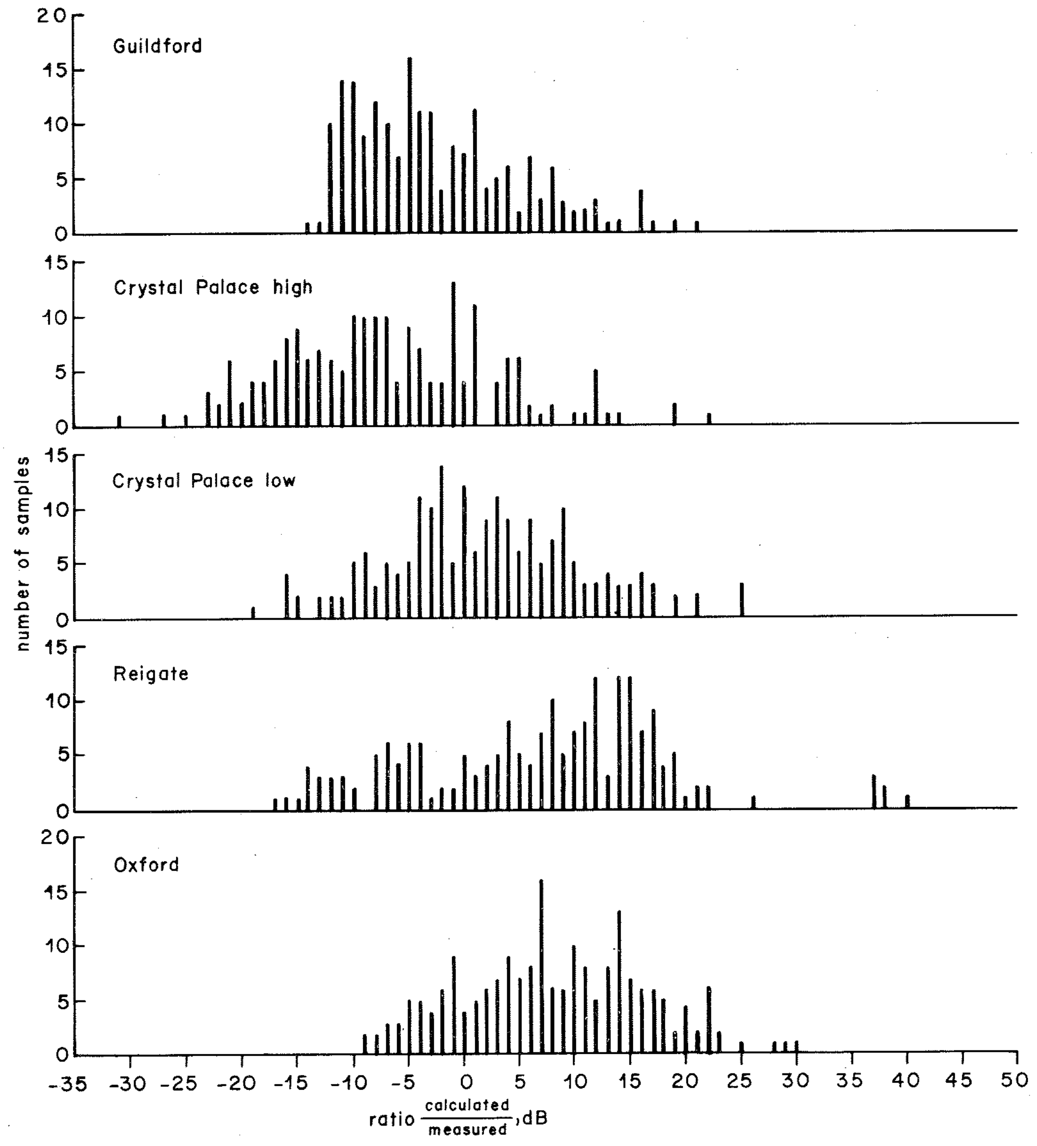


Fig. 12 - Histogram of differences between measured field strengths and those calculated using the c.c.i. prediction method

Some consideration was then given to established methods of prediction used elsewhere, notably those proposed by Epstein and Peterson,[5] by Longley and Rice,[6] and by the Ministry of Postal Services, Tokyo, Japan.[7] None of these proved to be immediately suitable for our purpose, in that their accuracy did not seem to be significantly better than domestic methods currently used. However, it was considered that the latter, which was a modification of the Epstein-Peterson approach, was sufficiently promising to justify further investigation with the objective of developing it to meet our requirements. This final stage of the examination is now in progress.

It is likely that the calculation will be in two parts. Firstly there will be the calculation of what may be termed the 'macroscopic' field strength. This would deal with the main features of the overall propagation path, and would produce a field strength which would be the modal value within a limited area, the size of the latter being dictated by the parameters used in the calculation. Secondly, the calculation would deal with the 'microscopic' field strength, which would be determined by influences in the immediate locality of the receiving site. The macroscopic part requires the calculation of multiple diffraction losses, and the profiles examined during the Guildford experiment have severely tested the various prediction methods. The Fresnel solution is adequate for one knife edge, but this can produce considerable errors if the obstacle has a smooth, rounded crest. Extension of the rigorous wave theory to deal with multiple edges is likely to give a complex general solution. Millington[8] has given the result for two edges, and has suggested that the Epstein-Peterson approximation should be used for paths with a greater number of diffractions. Hacking[9,10], has pointed out that the Japanese method results in a close agreement with the rigorous solution, and can be derived using Keller's geometrical theory of diffraction. However, it employs the asymptotic approximation for Fresnel loss, thus its accuracy is limited to those diffraction calculations where $v \geqslant 1$, v being the Fresnel limit parameter. Means of dealing with values of $v < 1$ are being devised and promising results are now being obtained.

So far the study has been concentrated upon the direct ray between terminal aerials; it has been concluded that inclusion in the calculation of both direct and reflected rays would only improve the answer in a small percentage of the total predicted. In order to achieve this marginal benefit it would be necessary to increase the quantity of stored data and to complicate the calculation very considerably. In this context, however, it must be remembered that the concentration is upon u.h.f. prediction, and any conclusion regarding the importance of reflection must be confined to these higher frequencies.

Present progress suggests a more accurate prediction system can be devised, but it will require extensive terrain data. Additionally, information concerning large trees may also be necessary, but fortunately it would seem that adequate data can be obtained from existing maps. To help the microscopic stage of the calculation, building data may be needed, and this presents difficulties. It may be possible to obtain some indication of the influence of buildings from a population count which it is hoped to include in the data storage, and this is being examined.

4. Other factors

4.1. General

The Guildford experiment was primarily directed towards investigation of the three items identified in the Introduction to this report. Two of these concern the application of prediction methods in current planning work, and this report has so far concentrated upon this aspect. Other features of transmitter network planning have necessarily been involved, and because they affect the choice of measurement or prediction, they are discussed here. The third objective was concerned with the correlation between field strengths measured from different sources, a study which concerns the multiple interference part of the c.c.i. calculation, and the significance of the Guildford results in this respect is considered.

4.2. Methods of service assessment

Basically, the planning of a network of transmitting stations consists of ensuring that the required service areas are achieved without causing interference elsewhere. In the absence of c.c.i., the minimum field strength required is established by factors such as receiver noise level, aerial gain and feeder loss, and may be regarded as constant throughout the service area. Where the c.c.i. results are in excess of this level, they dictate the minimum field strength requirements. Their accurate assessment is therefore important because they influence almost every factor involved in this stage of the planning – transmitting site, e.r.p., aerial characteristics and height, polarisation and choice of frequency. At present, the assessments of wanted service and c.c.i. levels for each station are carried out separately, and the two results compared, but for some time it has been realised that there is one important flaw in this process. This concerns the unbalance between information describing the service area and calculations which estimate the interference levels, and evidence from the Guildford results suggests this discrepancy can be quite serious. Measurements or predictions of the service area are usually completed in considerable detail, and these show the extent of field strength variation throughout the service area. They may outnumber the c.c.i. calculations by more than 100 : 1, because, as already explained, the interference predictions must be limited in number. Thus the relationship between the level of the wanted signal and that of the interference becomes largely a matter of conjecture and individual expertise on the part of the planning engineer. Existing results from the c.c.i. work show that well over one-third of the receiving sites used in the planning calculations to the present time have c.c.i. values in excess of the theoretical noise levels which apply to the u.h.f. bands (62 dBμ for Band IV and 67 dBμ for Band V). These results have been obtained for a planned network which, as yet, contains less than one-half of the final number of stations, so it is likely that the proportion of sites which could be affected by c.c.i. will increase substantially. There is, therefore, a real need to increase the density of the c.c.i. investigation.

Of course, the situation outlined above is not new. We were equally uncertain about the v.h.f. television network, but the risk is far greater with the u.h.f. service, simply because there may be something like five or six times the number of stations, and less than 1·5 times the number of frequency channels per programme.

The work on variation of field strength with receiving location has emphasised the need not only to increase the number of c.c.i. calculations, but also to improve the way in which they are compared with the levels of the wanted service. This can be achieved by calculating the latter as part of the c.c.i. assessment, so that direct comparison is possible. Where measurements of the wanted service are still considered necessary, comparison of these with the predictions will provide an indication of local accuracy.

A considerable part of the Guildford experiment has been devoted to the question of accuracy, both of prediction and of measurement. The basic error of measurement was given limits of ±5 dB, but mention was also made of a further error which could be introduced at the stage when measurements (or predictions) were being used to produce a field strength map. Such a map is a popular way of showing the coverage of a station, although it is often an oversimplification. However, such maps are required, and it is appropriate to consider the errors introduced during their preparation.

Currently, the method of measurement employed by the BBC is designed to reproduce, with high accuracy, the position of the limiting field strength contour for each transmitting station. The method is a compromise between the technique known as 'chase the contour' and the other extreme which has been called 'blanket survey'. In the former, measurements are made with the objective of locating a particular field strength contour, and as a result the contour can be positioned precisely. This method has the obvious disadvantage that information is limited, and the influence of any large change of e.r.p. might be difficult to define. Conversely, 'blanket' measurements provide overall information, but the positioning of a particular contour could be subject to error. In current BBC work, measurements are made in considerable density along the contour, but are also made at lower density elsewhere. As a result, errors in the map production are kept to a minimum. In this respect, evidence of the extent of this error (which may be referred to as 'technique error') has been obtained from the 1957 and 1969 field strength surveys made in Guildford of the Crystal Palace transmissions. Transmission conditions were nearly identical, except that the frequency of the 1957 transmitter was about 80 MHz higher. Firstly, a survey map was drawn, based on the blanket measurements made in 1969, the field strength contours being inserted at intervals of 10 dB. The 1957 results were then superimposed on this map, and it was found that only 110 of the 200 points fitted into the appropriate field strength intervals produced on the evidence of the 1969 survey. This is a disappointing result, but indicates the extent of the technique error which can occur if measurements are not concentrated in the vicinity of the contour. However, it was mentioned above that the ordinary field strength contour map probably oversimplifies the information concerning coverage in order to present the basic data clearly. A likely outcome of a new prediction method which would produce comparisons of the wanted signal and the interference would be some different way of illustrating the coverage. Several alternatives have already been postulated and will be examined.

4.3. Multiple interference

The third objective of the Guildford experiment concerned the correlation between signals, and was directed towards improving the present method used for calculating multiple interference levels. At present this method,[11] which is used to complete the calculation of c.c.i., employs the multiplication of probabilities of interference. It has received much criticism in the past, but so far a better technique has not been put forward. In outline, the variables of each signal, time and location, are combined to form one distribution expressing variation in terms of a single parameter known as 'time-location'. The multiplication process consists of the combination of these individual distributions, each representing one interfering signal, to form a single distribution, still in the time-location frame. The final stage, and the one which attracts most argument, involves the separation of this distribution into its component parts, time and location. This permits the result to be quoted as x% locations protected against c.c.i. for y% of the time.

Apart from the objection which may be directed towards the final stage, the Guildford experiment has confirmed earlier suspicions regarding the distribution of field strength values with respect to location. For the purposes of the calculation it is necessary to assume that the distribution observes a log-normal law, and measurements over a very limited area have confirmed that this is true, unless there is some local influence such as a building which attenuates the signal and hence introduces a degree of skewness. If, however, measurements made in the shadow of local obstacles are discounted, a log-normal distribution may result from measurements made over a considerable area, until receiving sites are reached which terminate substantially different propagation paths to those previously measured. For example, a distant hill may cause marked attenuation, and measurements in this shadow will probably observe their own log-normal distribution, but several decibels below that measured at adjacent open sites. It will be realised that when transmissions from several sources are being measured, the likelihood of obtaining log-normal distributions for all of these within the same area is small. The size and shape of each area will be governed by the transmission source, and as a result of this it is impossible to assign geographical limits to the answer produced from the multiple interference calculation. In view of this, it would seem realistic to limit the process to deal only with variation in time. This does not mean that variation with location does not exist, but simply that the calculation is based upon median values in this domain, and greater detail is impracticable. Furthermore, if the density of investigation is increased by carrying out more c.c.i. calculations, a more useful result is obtained. Of course, the elimination of one variable from the multiple interference stage would also allow simpler methods to be used, for example, power addition.

Work on the correlation coefficients both in time and location which forms part of the Guildford experiment will be useful in improving the multiple interference calculation. Furthermore, it is likely that it will help to add meaning to the present definitions of interference. For example, the present c.c.i. calculations are directed towards achieving protection against interference for '95% of the time'. The real usefulness of this term is to tell the engineer which propagation curves should be used. In considering the correlation between signals, and the way in which this varies with the period of observation, it is possible that definitions could be made more precise.

5. Discussion

5.1. Adequacy of present prediction methods

Dealing firstly with the examination of the service area calculation method used by Research Department, the Guildford experiment has added some evidence to that already gathered concerning the accuracy of the system. Whether or not the overestimation of field strength noted for one part of the city is due to a systematic error is not clear, but this appears to be a weakness of the present system. Apart from this, the method appears to be capable of providing the type of outline information required to specify a u.h.f. relay station, and subject to the decision of the engineer undertaking the work (because he will be aware of any shortcomings of the method and the peculiarities of each station) can replace a site test. Of course, in common with any prediction method it cannot be used to check the operation of the eventual transmitting installation. To do this, site test measurements made before the station is constructed are checked against subsequent survey results, so that the performance of the transmitter and the aerial may be established. However, the need to carry out this sort of check is much less at relay stations than at main stations, because the equipment at the former tends to be standardised.

As far as the c.c.i. calculation is concerned, the present method is still not providing the accuracy which is needed if maximum economy in channels and expenditure is to be achieved. The quantity of results is currently limited, and it is generally necessary in practice to assume a pessimistic c.c.i. figure. This could mean that we are over-powering some of our u.h.f. transmitters, which means excessive expenditure and unnecessarily increases interference elsewhere. Equally serious is the situation identified by the Crystal Palace (high aerial) result, in which clutter loss is erroneously applied, and the c.c.i. is underestimated.

Improvements to the present c.c.i. method could probably be realised by devising empirical corrections which would evaluate local field strength variations. Also the density of results could be increased, although this would require a corresponding increase in the data required, and the present system is rather inflexible in this respect. In view of this and the need to achieve better correspondence between the assessments of wanted and unwanted signals, the introduction of a completely different prediction method which would replace both of the existing programmes is thought to be the better solution.

5.2. Future development

As an outcome of the experiment it has been concluded that substantial improvements to the prediction work can be realised, provided adequate data concerning terrain and other influential features are available. In this connection it is noteworthy that a project is being sponsored by the Joint Radio Committee of the Nationalised Power Industries,[12] to obtain and store height data for the majority of the United Kingdom, using a grid with intervals of 0·3 mile (0·5 km). At u.h.f. it is likely that in areas where predictions will be required the density of this grid will need to be increased, and it is believed that in such places the intervals will have to be halved, i.e., to 0·15 mile (0·25 km). This would provide a density of results higher than that used in the Guildford experiment, and is equal to the maximum density now used for measurement work.

Because the calculation will cover both wanted and interfering signals, full terrain information is unlikely to be used for all the propagation paths involved. In any case, beyond the range of about 60 miles (100 km), vagaries of the troposphere cause a considerable degree of fading, and this cannot yet be predicted accurately. Thus, at this range (if not before), it will be necessary to return to a statistical method such as that now used for the c.c.i. calculations. However, present evidence suggests that it is more important to achieve good accuracy for short-range paths in view of the risk of continuous interference that they involve.

Over the past two or three years there has been considerable growth in the size of data storage facilities. This means that it is not only possible to consider the storage of terrain data, but also the inclusion of a population store. Whether or not this would be useful for the calculation is not yet clear, but it will offer the additional advantage of providing consistent population counts, an important part of u.h.f. planning. Means of obtaining a population grid at the same density as that used for the terrain store have been devised, and proposals for dealing with the 1966 Census data in this way have been formulated. The next Census, in 1971, will take two years to process, and the information will not be available until 1973.

Of course, the future of the whole project depends upon the ability to produce an acceptable prediction method. Inevitably, the success of this must be judged on the comparison with measured results, although there are other advantages associated with the use of prediction. However, dealing firstly with the accuracy of prediction, it is useful to review the various comparisons which this report has produced. In each case the result has been measured by the standard deviation of the distribution produced by comparison with earlier measurement.

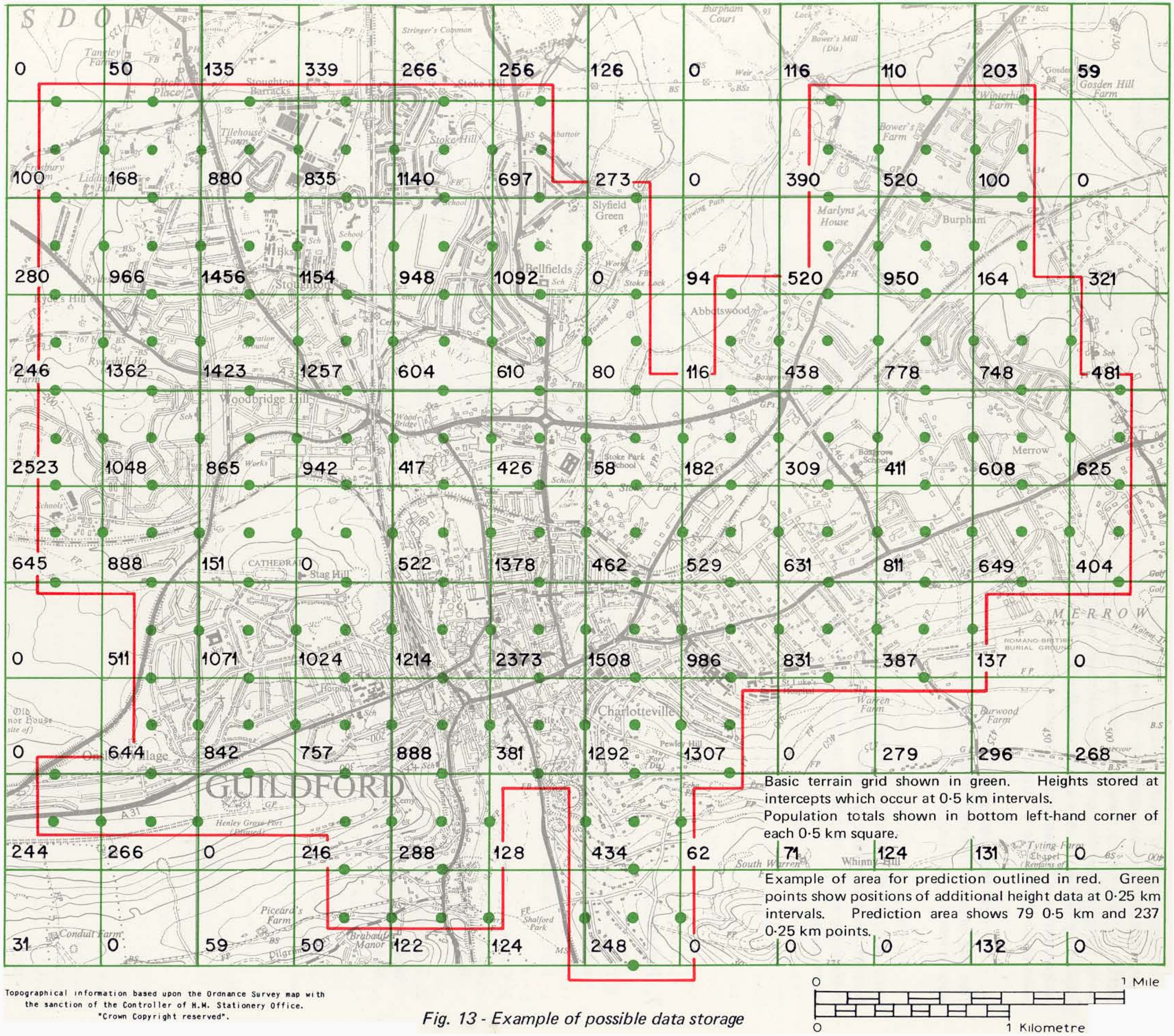
In the case of measurement itself, it has been concluded that the highest accuracy that can be realised in practice produces a standard deviation of 2 dB. If a small latitude of movement is allowed, this increases to a figure of about 4·5 dB. For prediction, the current method used for service area assessment has, in this experiment, produced a value of about 6·5 dB, and it is also recorded that in a very detailed examination carried out two years ago with the object of improving the method the result was 7 dB.[13] When used for the calculation of median values (in location), the c.c.i. method also gives a standard deviation of 7 dB[3], although when it is extended in an attempt to predict the detailed variations of field strength it becomes prone to considerably greater error, as shown in this report. In such circumstances a value of 10 dB can result.

Currently it is believed that a method of prediction can now be devised which will give a standard deviation between 6 and 7 dB. Although this is not as good as the best results so far obtained for prediction, it will possess the enormous advantage of allowing a 1 : 1 comparison to be made between wanted and interfering signals. Its accuracy in assessing the field strength values will not be far short of present measurement methods, and it will be consistent. It is also likely that results can be obtained in far greater density than is currently possible. It is not, however, possible to assess the cost of such a method until the system has been proved and computer running time has been estimated. However, because the method will provide a more precise picture of the effect of c.c.i. on the developing u.h.f. service, requirements for transmitting stations can be more accurately defined, and this is likely to result in some economy.

Figure 13 shows an example of the data which would be stored in the system now being planned. It also provides an indication of the density of prediction which it is hoped to achieve if proposals prove feasible.

6. Conclusions

The Guildford experiment has confirmed the need to improve the means of predicting c.c.i. on the u.h.f. service.



0	50	135	339	266	256	126	0	116	110	203	59
100	168	880	835	1140	697	273	0	390	520	100	0
280	966	1456	1154	948	1092	0	94	520	950	164	321
246	1362	1423	1257	604	610	80	116	438	778	748	481
2523	1048	865	942	417	426	58	182	309	411	608	625
645	888	151	0	522	1378	462	529	631	811	649	404
0	511	1071	1024	1214	2373	1508	986	831	387	137	0
0	644	842	757	888	381	1292	1307	0	279	296	268
244	266	0	216	288	128	434	62	71	124	131	0
31	0	59	50	122	124	248	0	0	0	132	0

Basic terrain grid shown in green. Heights stored at intercepts which occur at 0·5 km intervals.
Population totals shown in bottom left-hand corner of each 0·5 km square.

Example of area for prediction outlined in red. Green points show positions of additional height data at 0·25 km intervals. Prediction area shows 79 0·5 km and 237 0·25 km points.

Topographical information based upon the Ordnance Survey map with the sanction of the Controller of H.M. Stationery Office.
"Crown Copyright reserved".

Fig. 13 - Example of possible data storage

It has also provided further evidence concerning other shortcomings in present methods. A new method of prediction is now being developed, and the opportunity is being taken of combining the calculations of wanted and interfering signals, a step which would allow direct comparison between the two and one which could lead to a considerable simplification in output.

The new techniques will certainly require more data than the present system, and information has been assembled concerning the acquisition of these.

If the project is successful, and attains the targets which now seem realistic, the increase in accuracy in field strength prediction will be reflected in improved efficiency in planning work. It is hoped to complete the work in the near future.

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APPENDIX I

Transmission Sources

Station	Frequency (MHz)	Tx. Ae. Ht.		Distance to Guildford	
		Ft. a.g.l.	m	miles	km
1969 Surveys:					
Crystal Palace	567·25	692	211	25·5	41
Crystal Palace	522·0	150	46	25·5	41
Reigate	807·25	166	51	16·3	26·2
Oxford	807·25	523	159	47·0	76
Guildford	671·25	166	51	1·7	2·7
1957 Survey:					
Crystal Palace	654·25	690	210	25·5	41

APPENDIX II

Visit to Ordnance Survey Headquarters, Southampton

The objects of the visit were firstly to discover what height information was available in digital form from the Ordnance Survey, and secondly to learn of their future plans.

Height information used by the Ordnance Survey may be divided into four categories:

(i) Bench marks
(ii) Spot heights
(iii) Trigonometrical points
(iv) Contours

Dealing with these separately — bench marks are given with extreme accuracy, a figure of 0·01 foot was quoted but there were reservations about this. They are confined to roads, and their density over the United Kingdom varies enormously. In Leicester (for example) there are about 80 bench marks to the square kilometre, whereas in other places there is none or only one or two to the square kilometre. The height information and location (in National Grid co-ordinates) are tabulated and published at 10/- per sheet. Each sheet can accommodate up to 13 bench marks, and is published for a particular square kilometre, this being the basic unit of area. Where the information is scarce, there may be only one or two heights on a sheet, whilst in other cases several sheets are required to list the bench marks for one square.

The bench mark data are being transferred onto magnetic tape. At present, about 70,000 square kilometres have been checked and stored, and a further 60,000 has been stored but has not yet been checked. About 80,000 squares are outstanding, and Northern Ireland will not be included in this storage. The process of conversion is slow, because it is the intention to check points by survey before storage. Like all other large-scale projects within the Ordnance Survey, they hope to finish by 1980.

Spot heights also occur on roads only, but are less accurate than bench marks. They are the points of inflection that are noted by the survey teams during their bench mark work. They are not published in useful form, except on the maps themselves. They are used by the survey teams for interpolation purposes in contour drawing. There was no indication of their total number.

Trigonometrical points are used for levelling work. They occur at positions of good all-round visibility, e.g., hill-tops, and as in the case of bench marks, they are determined with considerable accuracy. They are not so numerous as bench marks, and apart from the fact that they are not limited to roads, add little overall information.

Contour information is separated into two types; those drawn during the survey, and those added subsequently. Obviously, those drawn during the survey are more accurate, because they are the results of expert analysis on the spot. Subsequent additions, such as the 25 ft. and 75 ft. intervals added to the 1/25,000 series of maps, may be less accurate. The registration accuracy quoted for contours on Ordnance Survey maps is plus or minus one half of the contour interval.

SMW/JUC